Multicarrier Effects in High Pulsed Magnetic Field Transport and Optical Properties of Mercury Cadmium Telluride

A thesis submitted for the degree of 'Doctor of Philosophy' in the Faculty of Sciences, IISc, Bangalore

by **Murthy O.V.S.N.**

Synopsis

This thesis on multicarrier effects in the magnetotransport and optical properties of Mercury Cadmium Telluride (MCT or HgCdTe) covers mainly: design, construction and calibration of a 12 T 4 K and 19 T 77 K pulsed high magnetic field systems; temperature dependent magnetotransport measurements upto 15T performed on the home-built pulsed magnet systems; computational techniques developed to extract densities and mobilities of various carriers, especially low mobility heavy holes, participating in conduction; theoretical analysis of heavy hole mobility based on Boltzmann transport equation; temperature dependent optical absorption experiments in the Mid and Far-IR on bulk and thin film samples; and theoretical modelling of optical absorption below bandgap. The work essentially probes the low and high frequency conductivity of the semiconductor alloy $Hg_{1-x}Cd_xTe$ by performing microscopic calculations of scattering related phenomena of its free carriers at higher temperatures (200 K–300 K) and comparing with experimental data. Special attention is given to properties of heavy holes as the effects due to these carriers appear only at higher magnetic fields. It is demonstrated that

in this temperature range and at high magnetic fields, taking both measured resistivity and derived conductivity in the multicarrier analysis gives better results which are then applied to explain both heavy hole mobility as well as free carrier absorption without further fitting parameters and using a minimal set of necessary intrinsic properties. The agreement thus obtained with experimental data is shown to be excellent. The bulk and epilayer samples used in this thesis were grown by the MCT group headed by R. K. Sharma (SSPL, Delhi). The organization of the thesis is as follows:

CHAPTER 1 The importance of Mercury Cadmium Telluride as a narrow gap semiconductor for infrared detection is introduced. The relevant physical and material properties of HgCdTe are reviewed.

CHAPTER 2 A low cost 12T pulsed magnet system has been integrated with a closed-cycle Helium refrigerator (CCR) for performing magnetotransport measurements. Minimal delay between pulses and AC current excitation with software lock-in to reduce noise enable quick but accurate measurements to be performed at temperatures 4K-300K upto 12T. An additional pulsed magnet operating with a liquid nitrogen cryostat extends the range upto 19T. The instrument has been calibrated against a commercial superconducting magnet by comparing quantum Hall effect data in a p-channel SiGe/Si heterostructure and common issues arising out of pulsed magnet usage have been addressed. The versatility of the system is demonstrated through magnetotransport measurements in a variety of samples such as heterostructures, narrow gap semiconductors and those exhibiting giant magnetoresistance.

CHAPTER 3 The necessity of employing multicarrier methods in magnetotransport of narrow gap semiconductors is brought out. In these materials, mixed conduction is seen to exist at nearly all temperatures of interest. Methods of extracting two of the most important transport parameters of device interest, density and mobility, from the variable magnetic field Hall and magnetoresistance measurements are elaborated. Improvements have

been made to the conventional non-linear least squares fitting procedure and are demonstrated.

<u>CHAPTER 4</u> Magnetotransport measurements in pulsed fields upto 15 Tesla have been performed on Mercury Cadmium Telluride ($Hg_{1-x}Cd_xTe$, x$\sim$0.2) bulk as well as liquid phase epitaxially grown samples to obtain the resistivity and conductivity tensors in the temperature range 220 K to 300 K. Mobilities and densities of various carriers participating in conduction have been extracted using both conventional multicarrier fitting (MCF) and Mobility Spectrum Analysis(MSA). The fits to experimental data, particularly at the highest magnetic fields, were substantially improved when MCF is applied to minimize errors simultaneously on both resistivity and conductivity tensors. The semiclassical Boltzmann Transport Equation (BTE) has been solved without using adjustable parameters by incorporating the following scattering mechanisms to fit the mobility: ionized impurity, polar and nonpolar optical phonon, acoustic deformation potential, alloy disorder. Compared to previous estimates based on the relaxation time approximation with out-scattering only, polar optical scattering and ionized impurity scattering limited mobilities are shown to be larger due to the correct incorporation of the in-scattering term taking into account the overlap integrals in the valence band.

<u>CHAPTER 5</u> Optical absorption measurements have been performed on bulk Mercury Cadmium Telluride ($Hg_{1-x}Cd_xTe$, x$\sim$0.2) samples between 4 K and 300 K. After fitting the Urbach part of the spectrum in the mid-infrared, below bandgap absorption is modeled using only basic processes and mechanisms, i.e. intervalence transitions and free carrier absorption (FCA). The additive FCA coefficients for individual carriers have been calculated using known quantum mechanically derived expressions for scattering due to polar and nonpolar optical phonons, ionized impurities and acoustic deformation potential mechanisms found to be relevant for electrical transport in this

temperature range. The densities of carriers used in the calculations are derived from a modified multicarrier fitting (MCF) procedure on both resistivity and conductivity tensors from magnetotransport measurements in pulsed fields upto 15 Tesla from 220 K to 300 K, thus making hole density more reliable. It is found that such a treatment is sufficient to model the absorption spectra below bandgap quite accurately without introducing any additional mechanical or compositional defect related phenomena.

CHAPTER 6 A summary of the work carried out in this thesis is presented. Some future directions including preliminary work to measure carrier mobilities at high electric fields and effect of hydrogen passivation in MCT are briefly discussed.

References:

Peer-reviewed Publications in Journals

1. "Construction and calibration of a 12 T pulsed magnet integrated with a 4 K closed-cycle refrigerator.", *O. V. S. N. Murthy*, & V. Venkataraman, Rev Sci Instrum, **78**, 11 (2007)

2. "A Closed-Cycle Refrigerator Based Pulsed Magnet", *O. V. S. N. Murthy*, & V. Venkataraman, Int. J. Mod. Phys B Vol 23, Nos. 12 and 13 (2009)

3. "Multicarrier Analysis of Magnetotransport Data at Low and High Electric Fields", *Murthy O. V. S. N.*, & V. Venkataraman, Phys. Status Solidi **C 6**, No. 6, 1505-1508 (2009)

4. "Multicarrier Conduction and Boltzmann Transport Analysis of Heavy Hole Mobility in HgCdTe near Room Temperature", *Oruganty V. S. N. Murthy*, V. Venkataraman, R. K. Sharma, I. Vurgaftman and J. R. Meyer, *accepted for publication in J. Appl. Phys., 2009*

Manuscript under preparation

1. "Multicarrier Effects in Free Carrier Absorption in Bulk HgCdTe", *Oruganty V. S. N. Murthy*, V. Venkataraman, R. K. Sharma, *to be submitted to Appl. Phys. Lett.*